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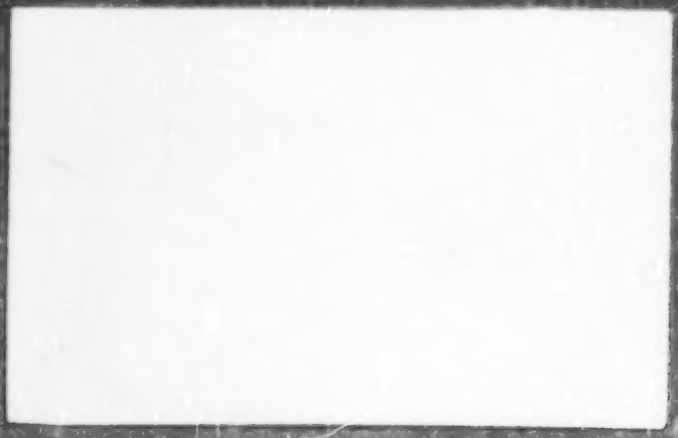
Physical and Chemical Parameters and Methods for Solid Waste Characterization

Bureau of Solid Waste Management

1970

PB 256 958



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PHYSICAL AND CHEMICAL PARAMETERS AND METHODS FOR SOLID WASTE CHARACTERIZATION

A Division of Research and Development
Open-File Progress Report (RS-03-68-17)

written by
Nancy S. Ulmer, Research Chemist and
Project Director (July 1967-July 1969)

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service
Bureau of Solid Waste Management
1970

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BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No. PB-256 958
4. Title and Subtitle: Physical and Chemical Parameters and Methods for Solid Waste Characterization			5. Report Date: 1970 6.
7. Author(s): Nancy S. Ulmer			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: Bureau of Solid Waste Management, Cincinnati, Ohio			10. Project/Task/Work Unit No. EPA-RS-03-68-17 11. Contract/Grant No.
12. Sponsoring Organization Name and Address			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstracts

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17. Key Words and Document Analysis. 17a. Descriptors

*Solid wastes,
*Chemical analysis,

Incinerators,
Carbon,
Hydrogen,
Nitrogen,
Physical properties,
Chemical properties,
Calorific value,
Ash content.

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group 13 B

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
National Technical Information Service Springfield, Virginia 22161	UNCLASSIFIED	28p
	20. Security Class (This Page) UNCLASSIFIED	22. Price 4.00/2.25

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

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ABSTRACT

The significance of eight parameters* in the characterization of solid wastes is being investigated. Laboratory studies have established methods for the precise and accurate determination of the biochemical oxygen demand of incinerator quench water and the carbon, hydrogen, and nitrogen contents of solid wastes collected before, during, and after processing. The value of determining these four parameters during the development, evaluation, and control of solid waste disposal systems is suggested. Other investigations, designed to elucidate the significance of the determination of the moisture, ash, volatiles, and calorific value of solid wastes, are in progress.

* In this paper the term parameter means a variable or characteristic of interest.

INTRODUCTION

Since World War II the population growth, urban sprawl, increased manufacture and sale of consumer goods, and the standard of living have been responsible for an ever-mounting increase in the mass and variety of materials being discarded in the United States. When the members of Congress found in 1965 that the disposal of solid wastes had become a problem of national scope and concern, they enacted the Solid Waste Disposal Act and thus provided for Federal "financial and technical assistance and leadership in the development, demonstration, and application of new and improved methods and processes to reduce the amount of waste and unsalvageable materials and to provide for proper and economical solid waste disposal practices."[1]

Objective scientific development, evaluation, and control of solid waste management systems depend upon the accurate characterization of solid wastes. Two research projects, namely, The Physical and Chemical Parameters of Significance in the Standard Characterization of Solid Wastes (RCP-01-68-01) and Methods for the Physical and Chemical Characterization of Solid Wastes (RCP-03-68-01) were therefore initiated in the laboratory of the Division of Research and Development, Bureau of Solid Wastes Management, in FY 68. The goals of these two projects were the determination, establishment, and publication of the physical and chemical parameters and methods for solid waste characterization. The initial investigations revealed the inter-dependence of the goals and progress of these two projects. They were thus combined into a single

project, Physical and Chemical Parameters and Methods for Solid Waste Characterization (RS-03-68-17).

The following report discusses the approach and results of the investigations performed from July 1, 1967, to July 1, 1969.

APPROACH AND RESULTS

Selection of Specific Parameters of Possible Significance in the Characterization of Solid Wastes

An extensive literature review was initiated early in FY 68 to gather knowledge relevant to solid waste characterization. A list of over 100 physical and chemical parameters, whose possible significance had been suggested in the literature, was then prepared (Table 1). A compilation of published parameter values, such as those presented in Tables 2 through 5, was also initiated. The physical and chemical parameter list and the tabulated data, together with the requests and suggestions of many scientists and engineers responsible for providing leadership and technical assistance in the development, evaluation, and control of solid waste disposal systems, were then utilized as guidelines in the selection of the first eight parameters, whose significance would be evaluated. The biochemical oxygen demand of incinerator quench water and the carbon, hydrogen, nitrogen, moisture, ash, volatile, and calorific contents of wastes before, during, and after processing thus became the subject of our laboratory investigations.

Selection, Development, Evaluation, and Publication of Methods for Solid Waste Characterization

To facilitate the immediate characterization of solid wastes by other investigators and the compilation of additional data, with which the significance of selected parameters could be established, efforts were then concentrated on investigations of analytical methods.

The American Public Works Association's tentative methods of analysis of refuse and compost provided a foundation and baseline for further research and development of analytical methods.[2] To date revisions in the tests for moisture, sugar, pH, calorific value, carbon, and hydrogen have been recommended.

Independent laboratory studies were then initiated to establish a method for the determination of each of the eight selected parameters. The objectives of each investigation included (1) a thorough literature review of existing analytical techniques; (2) the selection or proposal of a universally feasible procedure; (3) the evaluation of the sensitivity, precision, and accuracy of the method in the characterization of solid wastes before, during, and after processing; and (4) the publication of two reports - - one, describing the objectives, approach, results, and conclusions of the investigation, and the other presenting the procedural directions for the determination of the specific parameter in solid wastes. The following paragraphs summarize the progress of the various method studies undertaken to date.

Biochemical Oxygen Demand (BOD) of Incinerator Quench Water. A brief evaluation of methods currently employed by the water pollution control laboratories, has culminated in the preparation of two papers: "Report on the Applicability of Existing Methods for the Determination of the Biochemical Oxygen Demand (BOD) of Incinerator Quench Water"[3] and "Laboratory Procedures for the Biochemical Oxygen Demand (BOD) Determination of Incinerator Quench Water."[4] These papers describe the establishment of the applicability of the Weston and Stack Dissolved Oxygen Meter* in the analysis of the BOD of quench water and the development of a simple procedure for checking the analyzer's performance in the field. Quick qualitative tests for evaluating the applicability of the Azide Modification of the Winkler Method are also presented in the papers.

Carbon and Hydrogen. A comprehensive literature review revealed that existing methods were not feasible for the determination of carbon and hydrogen in heterogeneous solid waste materials. A modified macroanalytical technique was proposed that utilizes a dry combustion-purification-gravimetric approach. Extensive study has demonstrated that the method can be employed to analyze precisely and accurately 1- to 2-g samples of uniform and thoroughly dried solid wastes having a total carbon content of 0.5 to 83.0 percent and a total hydrogen content of 0.01 to 7.30 percent. Three papers have been prepared--the first is a "Report on the Development of a Method for the Determination of Carbon and Hydrogen

*Product (or manufacturer) designation within this report does not imply endorsement by the Public Health Service.

in Solid Wastes"[5], and the second[6] and third[7] are descriptions of the method planned for publication in a scientific journal and laboratory method manual respectively.

Nitrogen. The applicability of the Kjeldahl-Wilfarth-Gunning-Winkler, Comprehensive Nitrogen, and Automated Dumas Methods in the determination of nitrogen in refuse, compost, incinerator residue, and fly ash were evaluated in the laboratory. The investigations demonstrated that the sample weight utilized in the analyses must be limited to 0.1g and 1.0 to 2.5 g respectively. Two papers, establishing the applicability and procedural directions for the three methods are currently being prepared for publication.[8,9]

Moisture. Initial laboratory studies demonstrated that the heterogeneous character and moisture content of solid wastes rendered methods such as the toluene-distillation and Karl Fischer titration impractical for the moisture characterization of refuse, compost, incinerator residue and fly ash. Attention was therefore directed to the evaluation of procedures that might be employed for the simultaneous characterization and preparation of large samples of solid wastes.

Preliminary investigation revealed that drying could be accomplished in a mechanically convected or forced-air oven at 70 C or 105 C, but the time required to obtain constant weight was often 18 to 24 hours. In an effort to shorten the drying period and increase the number and size of samples that could be processed each day, investigations of other drying

procedures were performed. Freeze-drying of 50- to 150-g refuse samples was accomplished in 7 hours using a small improvised apparatus. The cost of an instrument capable of freeze-drying a number of larger samples per day renders this approach impractical for the average laboratory. Vacuum-drying of solid wastes, i.e., drying in a 70 C or 105 C oven at a gauge pressure of 1 to 15 in. of mercury, yielded similar data and appears to be more economically feasible. Recent observations of the relationship between (1) the particle size or exposed surface area of the solid waste, and (2) the drying period required to achieve constant weight have suggested the performance of additional research before the formulation of conclusions and the publication of recommendations.

Ash and Volatiles. Laboratory studies were initiated in FY 68 to evaluate the applicability of various muffle furnace procedures in the determination of ash and volatiles of solid wastes. The effects of the following variables upon the observed percents ash and volatiles have been ascertained: the type and size of apparatus, the sample weight, the amount of exposed sample surface area, the initial oven temperature, the muffling temperature, and the length of the muffling period. The effects of sample heterogeneity must be evaluated in the future. After sample preparation techniques have been sufficiently perfected to ensure the representative nature of 200-mg (or less) solid waste samples, the utilization of a thermogravimetric-gas chromatographic procedure should also be considered. This approach would afford a more rapid and complete characterization of the volatiles than can be obtained by the muffle

furnace technique.

Calorific Value. Investigations of the applicability of the Parr Adiabatic Calorimeter Procedure[10] in the determination of the calorific value of solid wastes were also initiated in FY 69. The studies to date have demonstrated that precise and accurate determinations of the calorific value of municipal refuse and compost may be obtained with this technique. Additional studies must be performed to elucidate a procedure for the determination of the calorific value of hard-to-combust incinerator residue and fly ash samples.

Establishment of the Significance of the Selected Parameters in the Characterization of Solid Wastes

The analytical observations made during the method research and the characterization studies were continuously added to the data compilation to facilitate the elucidation and establishment of the significance of the selected parameters in the characterization of solid wastes. The June 30, 1969, tabulation of the range of values for 31 parameters (Table 6) therefore included the data obtained during the in-house analyses of (1) refuse and compost collected at composting facilities in Johnson City (Tennessee), and Gainesville and St. Petersburg (Florida), and (2) refuse, incinerator residue, fly ash, and related samples collected at incinerator facilities in the District of Columbia, Ogden (Utah), Alexandria (Virginia), New York, Memphis, Cincinnati, Atlanta, and New Orleans.

The tabulated data was periodically reviewed to detect significant

changes in the character of solid wastes and related samples during composting, incineration, and landfilling. Analytical observations to date have revealed, for example, a 100- to 300-ppm increase in the biochemical oxygen demand of tap water after its use for quenching incinerator residue. Since the disposal of such quench water may pollute the receiving waterway, determinations of the biochemical oxygen demands of the quench water and the receiving medium should be included in the characterization studies performed during the development, evaluation, and control of incineration processes. Analyses of the additional data, thus obtained, would then afford a more complete elucidation of the significance of this parameter.

Additional review of the tabulated parameter values has also suggested that the observed concentrations of carbon, hydrogen, and nitrogen reflect the degree and rate of decomposition of the organic matter in the refuse. It is proposed that these three parameters be included in the solid waste characterizations performed during the development, evaluation, and control of solid waste disposal systems.

Compost research has, in fact, already suggested that the concentrations of carbon and nitrogen and the change in the C/N ratio can be used to evaluate (1) the degree and rate of biological decomposition of the organic matter in compost,[11, 12] and (2) the suitability of the final product for use in agricultural soils.[13] Knowledge of the carbon, hydrogen, and nitrogen contents of the input and observed combustion products of an incinerator may also enable the analyst to (1) calculate

the theoretical air requirements and combustion products, (2) formulate appropriate material and energy balance equations, and (3) evaluate and control more effectively the efficiency of an incineraton system.[14]

The significance of these and other parameters in the characterization of solid wastes cannot be established completely until the recommended characterizations have been tested by use in the development, evaluation, and control of a number of similar solid waste disposal systems.

SUMMARY

Research studies were initiated to establish parameters and methods for the characterization of solid wastes before, during, and after processing to assist the objective scientific development, evaluation, and control of solid waste systems. Eight parameters (biochemical oxygen demand, carbon, hydrogen, nitrogen, moisture, ash, volatiles, and calorific value) were selected from a list of over 100 physical and chemical parameters of possible significance in the characterization of solid wastes. Methods for the determination of the biochemical oxygen demand of quench water and the carbon, hydrogen, and nitrogen contents of solid wastes were established in the laboratory. Evaluation of procedures for the determination of the other four parameters are in progress. The significance of the determination of (1) the biochemical oxygen demand of quench water and the carbon, hydrogen, and nitrogen contents of solid wastes during the development, evaluation, and control of incineration

processes and (2) the carbon and nitrogen contents and C/N ratios of solid wastes during the evaluation of composting processes has been suggested.

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ACKNOWLEDGMENTS

The progress reported herein is the product of a team effort. Israel Cohen, James Jacob, Annella Johnson, William Kaylor, Vince Lewis, Richard Lossin, Robert Thurnau, and Donald Wilson have made significant contributions in the development of methods for the characterization of solid wastes. Albert J. Klee and the staff of the Operational Analysis Branch of the Division of Technical Operations developed computer programs and performed special statistical analyses.

TABLE 1

GENERAL, PHYSICAL, AND CHEMICAL PARAMETERS OF POSSIBLE SIGNIFICANCE IN THE CHARACTERIZATION OF SOLID WASTES BEFORE, DURING, AND AFTER PROCESSING

General parameters

Compositional types (%)	Process types (%)
Paper	Combustible
Garbage (food, grass, leaves)	Compostable
Rags	Processable by landfill
Glass	Salvagable
Ceramics	Having intrinsic value
Plastics	
Rubber	
Leather	
Ferrous metals	
Tin cans	
Wood (limbs, sawdust)	
Bricks, stones, dirt, ashes	

Physical parameters

Total wastes	Solid wastes	Liquid wastes	Gas wastes
Size	Soluble (%)	Turbidity	Temperature
Shape	Suspendable (%)	Color	Pressure
Volume	Combustible (%)	Taste	Volume
Weight	Volatile (%)	Odor	Density
Density	Ash (%)	Temperature	Particulate (%)
Density stratification	Soluble (%)	Vicosity	Liquid (%)
	Suspendable (%)	Density	
Surface area	Hardness (scale, 1 to 10)	Density stratification	
Compaction	Calorific value	Total solid (%)	
Compactability	Particle size	Soluble (%)	
Temperature	" shape	Suspendable (%)	
Color	" surface	Dissolved oxygen	
Odor	" porosity		
Age	" sorption		
Radioactivity	" density		
Beta emission	" aggregation		
^{226}Ra			
^{90}Sr			
^{40}K			
Physical state			
Total solids			
Liquid			
Gas			

Chemical parameters

General

pH
Alkalinity
Hardness ($CaCO_3$)
MBAS (methylene blue active substances)
BOD (biochemical oxygen demand)
COD (chemical oxygen demand)
Rate of availability of nitrogen
Rate of availability of phosphorus
Crude fiber
Organic (%)

Organic

Soluble (%)
Protein nitrogen
Non-protein nitrogen
Phosphorus
Lipids
Starches
Sugars
Hemicelluloses
Lignins
Phenols
Benzene oil
ASB (alkyl benzene sulfonate)
CCE (carbon chloroform extract)
Vitamins (eg., B-12)
Insecticides (eg., Heptochlor, DDT, Dieldrin, etc.)

Inorganic and elemental

Moisture content (water)
Carbon
Hydrogen
C/H ratio
Nitrogen as NH_3
Nitrogen as nitrates of calcium, magnesium, sodium, potassium
Nitrogen as nitrites
C/N ratio
C/N ratio changes
Potassium (K_2O)
Phosphorus (P_2O_5 and phosphate)
Calcium
Magnesium
Aluminum
Iron
Manganese
Sulfur
Sodium
Copper
Zinc
Chromium
Nickel

Silicon
Selenium
Antimony
Mercury
Arsenic
Beryllium
Cadmium
Lead
Barium
Silver
Boron
Chloride
Fluoride
Sulfate
Carbonate
Bicarbonate
Asbestos
Oxygen
Carbon monoxide
Carbon dioxide
Sulfur dioxide
Sulfur trioxide
Nitrogen dioxide

TABLE 2

COMPOSITION AND ANALYSIS OF AN AVERAGE MUNICIPAL REFUSE*

	Per cent of total refuse	Proximate Analysis† "As received" basis, weight per cent. Moisture	Volatile Matter	Fixed Carbon	Non-Comb.‡	Ultimate Analysis, Dry basis, weight per cent. Carbon	Total Hydrogen	Available Hydrogen	Oxygen	Nitrogen	Sulfur	Non-Comb.‡	Ratio C:(H)	Btu per lb Dry basis	Btu per lb Dry, ash-free basis
Rubbish, 64%															
Paper, mixed	42.0	10.24	75.94	8.44	5.38	43.41	5.82	(0.28)	44.52	0.25	0.20	6.00	155	7572	8055
Wood and bark	2.4	20.00	67.89	11.31	0.80	50.46	5.97	(0.672)	42.37	0.15	0.05	1.00	75	8613	8700
Grass	4.0	65.00	--	--	2.37	43.33	6.04	(0.85)	41.68	2.15	0.05	6.75	92	7695	8250
Brush	1.5	40.00	--	--	5.00	42.52	5.90	(0.75)	41.20	2.00	0.05	8.33	56.7	7900	8600
Greens	1.5	62.00	26.74	6.52	4.94	40.31	5.64	(0.77)	39.00	2.00	0.05	13.00	52.4	7077	8135
Leaves, ripe	5.0	50.00	--	--	4.10	40.50	5.95	(0.51)	45.10	0.20	0.05	8.20	131	7069	7700
Leather	0.3	10.00	68.46	12.44	9.10	60.00	8.00	(6.56)	11.50	10.00	0.40	10.10	9.1	8850	9850
Rubber	0.6	1.20	85.98	4.94	9.88	77.65	10.35	(10.35)	-	-	2.0	10.00	7.5	11330	12600
Plastics	0.7	2.00	--	--	10.00	60.00	7.20	(4.40)	22.60	-	-	10.20	13.6	14368	16000
Oils, paints	0.8	0.00	--	--	16.30	66.85	9.65	(9.00)	5.20	2.00	-	16.30	7.43	13400	16000
Linoleum	0.1	2.10	64.50	6.60	26.80	48.06	5.34	(5.00)	18.70	0.10	0.40	27.40	16	8310	11450
Rags	0.6	10.00	84.34	3.46	2.20	55.00	6.60	(2.70)	31.20	4.62	0.13	2.45	20.4	7652	7844
Sweepings, Street	3.0	20.00	54.00	6.00	20.00	34.70	4.76	(0.56)	35.20	0.14	0.20	25.00	96	6000	8000
Dirt, Household	1.0	5.20	20.54	6.26	70.00	20.62	2.57	(2.07)	4.00	0.50	0.01	72.30	10	5790	13650
Unclassified	0.5	4.00	--	--	60.00	16.60	2.45	(0.166)	18.35	0.05	0.05	62.50	100	5000	8000
Food wastes, 12%															
Garbage	10.0	72.00	20.26	3.26	4.48	44.99	6.43	(2.845)	28.76	3.50	0.32	16.00	15.8	8484	10100
Fats	2.0	0.00	--	--	0	76.70	12.10	(10.70)	11.20	0	0	0	7.2	16700	16700
Noncombustibles, 24%															
Metallics	8.0	3.00	0.5	0.5	96.0	0.76	0.04	(0.02)	0.2	-	-	99.0	51	124	12000
Glass and ceramics	6.0	2.00	0.4	0.4	97.2	0.56	0.05	(0.02)	0.11	-	-	99.3	34	65	8000
Ashes	10.0	10.00	2.68	24.12	63.2	28.0	0.5	(0.40)	0.8	-	0.5	70.2	70	4172	14000
	100.0														

Organic Analysis of Composite

	Per cent
Moisture	= 20.75
Cellulose, sugar, starch	= 46.65
Lipids(fats, oils, waxes	= 4.50
Protein, 6.25N	= 2.05
Other organic (plastics)	= 1.15
Ash, metal, glass, etc.	= 24.90
	100.00

Analysis of Composite Refuse, As Received Basis

Moisture	Carbon	Total Hydrogen	Available Hydrogen	Oxygen	Nitrogen	Sulfur	Non-Comb.	Ratio C:(H)	Btu per lb
20.75	28.00	3.50	(0.71)	22.35	0.33	0.16	24.90	33.4	4917

Btu, dry 6205
Btu, M and AF 5048

*Source: Bell, J.M. Characteristics of municipal refuse. In Proceedings; national conference on solid waste research. Chicago, American Public Works Association, December 1963. p. 37.

†Based on ASTM methods of analysis of coal and coke, as adapted for refuse.

‡Non-combustibles: ash, metal, glass and ceramics.

TABLE 3

PROXIMATE ANALYSES OF COMBUSTIBLE COMPONENTS OF MUNICIPAL REFUSE IN PERCENT BY WEIGHT, AS DISCARDED (A.D.) BY HOUSEHOLDERS*

Refuse Component	Moisture	Volatile Matter	Fixed Carbon	Ash	Btu/lb A.D.	Btu/lb Dry Basis
1. Newspaper	5.97	81.12	11.48	1.43	7974	8480
2. Brown paper	5.83	83.92	9.24	1.01	7256	7706
3. Trade magazine	4.11	66.39	7.03	22.47	5254	5480
4. Corrug. paper boxes	5.20	77.47	12.27	5.06	7043	7429
5. Plastic coated paper	4.71	84.20	8.45	2.64	7341	7703
6. Waxed milk cartons	3.45	90.92	4.46	1.17	11327	11732
7. Paper food cartons	6.11	75.59	11.80	6.50	7258	7730
8. Junk mail	4.56	73.32	9.03	13.09	6088	6378
9. Veget. food wastes	78.29	17.10	3.55	1.06	1795	8270
10. Citrus rinds and seeds	78.70	16.55	4.01	0.74	1707	8015
11. Meat scraps, cooked	38.74	56.34	1.81	3.11	7623	12443
12. Fried fats	0.00	97.64	2.36	0.00	16466	16466
13. Leather shoe	7.46	57.12	14.26	21.16	7243	7826
14. Heel and sole composition	1.15	67.03	2.08	29.74	10899	11026
15. Vacuum cleaner catch	5.47	55.68	8.51	30.34	6386	6756
16. Evergreen shrub cuttings	69.00	25.18	5.01	0.81	2708	8735
17. Balsam spruce	74.35	20.70	4.13	0.82	2447	9541
18. Flower garden plants	53.94	35.64	8.08	2.34	3697	8027
19. Lawn grass	75.24	18.64	4.50	1.62	2058	8312
20. Ripe tree leaves	9.97	66.92	19.29	3.82	7984	8869

*Source: Kaiser, E. R. Chemical analyses of refuse components. In Proceedings of 1966 national incinerator conference. New York City, The American Society of Mechanical Engineers, May 1966. p. 85.

TABLE 4

ULTIMATE ANALYSES OF COMBUSTIBLE COMPONENTS OF MUNICIPAL REFUSE IN PERCENT BY WEIGHT, DRY BASIS*

Refuse Component	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
1. Newspaper	49.14	6.10	43.03	0.05	0.16	1.52
2. Brown paper	44.90	6.08	47.84	0.00	0.11	1.07
3. Trade magazine	32.91	4.95	38.55	0.07	0.09	23.43
4. Corrug. paper boxes	43.73	5.70	44.93	0.09	0.21	5.34
5. Plastic coated paper	45.30	6.17	45.50	0.18	0.08	2.77
6. Waxed milk cartons	59.18	9.25	30.13	0.12	0.10	1.22
7. Paper food cartons	44.74	6.10	41.92	0.15	0.16	6.93
8. Junk mail	37.87	5.41	42.74	0.17	0.09	13.72
9. Veget. food wastes	49.06	6.62	37.55	1.68	0.20	4.89
10. Citrus rinds and seeds	47.96	5.68	41.67	1.11	0.12	3.46
11. Meat scraps, cooked	59.59	9.47	24.65	1.02	0.19	5.08
12. Fried fats	73.14	11.54	14.82	0.43	0.07	0.00
13. Leather shoe'	42.01	5.32	22.83	5.98	1.00	22.86
14. Rubber composition heel and sole	53.22	7.09	7.76	0.50	1.34	30.09
15. Vacuum cleaner catch	35.69	4.73	20.08	6.26	1.15	32.09
16. Evergreen trimmings	48.51	6.54	40.44	1.71	0.19	2.61
17. Balsam spruce	53.30	6.66	35.17	1.49	0.20	3.18
18. Flower garden plants	46.65	6.61	40.18	1.21	0.26	5.09
19. Lawn grass, green	46.18	5.96	36.43	4.46	0.42	6.55
20. Ripe tree leaves	52.15	6.11	30.34	6.99	0.16	4.25

*Source: Kaiser, E.R. Chemical analyses of refuse components. In Proceedings of 1966 national incinerator conference. New York City, The American Society of Mechanical Engineers, May 1966. p. 86.

TABLE 5

ANALYSES OF A COMPOSITE MUNICIPAL REFUSE*

Proximate analysis	
Moisture	20.00 percent
Volatile matter	52.70
Fixed carbon	7.30
Ash and metal	20.00
	100.00 percent
Btu/lb: 5260 + 182† = 5442	
Ultimate Analysis	
Moisture	20.00 percent
Carbon	29.83
Hydrogen	3.99
Oxygen	25.69
Nitrogen	0.37
Sulfur	0.12
Ash and metal	20.00
	100.00 percent

*Source: Kaiser, E.R. Chemical analyses of refuse components. In Proceedings of 1966 national incinerator conference. New York City, The American Society of Mechanical Engineers, May 1966. p. 87.

†From 50 percent oxidation of metals.

TABLE 6

RANGE OF VALUES OF SOME PHYSICAL AND CHEMICAL PARAMETERS OF SOLID WASTES AND RELATED SAMPLES*

June 30, 1969

Parameter			Type of Sample						
Identity	Unit of measurement	Basis of measurement	Municipal refuse	Compost	Incinerator residue	Fly ash	Scrubber water	Quench water	Land surface water
Alkalinity ($CaCO_3$)	mg/l	As rec'd	-	-	-	-	0-237	68-1290	1040
Ash	%	As rec'd		5.24-29.63			-	-	-
	(w/w)	Dry	4.0-37.9	22.7-55	27.7-96.2	72.5-97.5	-	-	-
	mg/l	As rec'd	-	-	-	-	16-6099	1100-2703	849-993
	%(w/w) of tot. solids	As rec'd					13.23-76.70	76.46-89.44	78.62-86

*Values presented reflect the number of analyses and degrees of accuracy reported in the following sources: Bell, J.M. Characteristics of municipal refuse. In Proceedings; national conference on solid waste research. Chicago. American Public Works Association, December 1963. p. 37. Fuller, W.H., and S. Bosma. The nitrogen requirements of some municipal composts. Compost Science, 6(2): 26-32, 1965. Kaiser, E.R. Composition and combustion of refuse. In speech presented at MECAR symposium on incineration of solid wastes. New York City, March 21, 1967. Personal communications. I. Cohen, A. Johnson, W. Kaylor, R. Lossin, and D. Wilson, Bureau of Solid Waste Management, 1968-1969. University of California, Reclamation of municipal refuse by composting. Institute of Engineering Research Technical Bulletin No. 9, Series 37. Berkeley, University of California, June 1953. p.47. Wiley, J.S. Refuse and sludge-refuse composting. Journal of Boston Society of Civil Engineers, 49(1):13-25, January 1962.

Parameter			Type of sample						
Identity	Unit of measurement	Basis of measurement	Municipal refuse	Compost	Incinerator residue	Fly ash	Scrubber water	Quench water	Land surface water
BOD	ppm	As rec'd						100-300	
Calorific value	BTU/lb	As rec'd	3000-6000				-	-	-
		Dry	5475-10,000	3920-7520	513-5245	275-1705	-	-	-
		MAF†	8100-9048		960-8980		-	-	-
Carbon, fixed	% (w/w)	As rec'd	4.83-6.70				-	-	-
		Dry	8.35-9.19				-	-	-
Carbon, total	% (w/w)	As rec'd	8.0-35.0	20.03-21.24			-	-	-
		Dry	26.5-47.68	19.1-43.58	0.58-1.27	3.00-4.42	-	-	-
		MAF	49.87-50.70				-	-	-
Chloride	mg/l	As rec'd	-	-	-	-	52-3821	50-3650	206-210
C/N‡	(ratio)	As rec'd		27.1-49.9			-	-	-
		Dry	20-78	17-45			-	-	-

†MAF = Moisture and ash free

‡The C/N values were taken directly from the literature; i.e., they were not calculated from the carbon and nitrogen values reported herein.

Parameter			Type of sample						
Identity	Unit of measurement	Basis of measurement	Municipal refuse	Compost	Incinerator residue	Fly ash	Scrubber water	Quench water	Land surface water
Conductivity	$\frac{\text{u mhos}}{\text{cm}}$	As rec'd	-	-	-	-	220-12,050	100-12,600	1550
Crude fiber	% (w/w)	As rec'd		19.26-20.93			-	-	-
Density	g/cc	As rec'd			0.42-1.39				
Hardness ($CACO_3$)	mg/l	As rec'd	-	-	-	-	77-3780	83-1574	631-645
Hydrogen	% (w/w)	As rec'd	2.44-3.37						
		Dry	4.22-6.40	2.17-6.04	0.01-0.09	0.09-0.17	-	-	-
		MAF	6.60-6.87				-	-	-
Lipids (Ether extract)	% (w/w)	As rec'd		0.5-8.0					
Moisture	% (w/w)	As rec'd	8.8-57.5	33.74-58.04	0.03-59.52	0.1-69.4	-	-	-
		Dry		33-32					

Parameter			Type of sample						
Identity	Unit of measurement	Basis of measurement	Municipal refuse	Compost	Incinerator residue	Fly ash	Scrubber water	Quench water	Land surface water
Nitrogen (N)	% (w/w)	As rec'd	0.2-3.0	0.43-0.74			-	-	-
		Dry	0.3-1.74	0.52-1.55[§]	0.08-0.75	0.01-0.07	-	-	-
		MAF	0.91-1.50				-	-	-
Oxygen	% (w/w)	As rec'd	14.48-22.35				-	-	-
		Dry	25.01-29.76				-	-	-
		MAF	40.72-42.44				-	-	-
pH	log 1/[H]	As rec'd	-	-	-	-	1.75-6.80	5.90-11.80	7.40
Phosphates ($PO_4^{\equiv}$)	mg/l	As rec'd	-	-	-	-	0.07-76.2	0-225.0	1.8-3.0
Phosphorus	% (w/w)	Dry	0.12-0.70	0.20-0.55			-	-	-
Potassium	% (w/w)	Dry	0.13-0.42	0.25-0.57			-	-	-
Protein (6.25 N)	% (w/w)	As rec'd		2.66-4.61			-	-	-

[§]Values for compost, fortified with ammonium nitrate, are not included.

Parameter			Type of sample						
Identity	Unit of measurement	Basis of measurement	Municipal refuse	Compost	Incinerator residue	Fly ash	Scrubber water	Quench water	Land surface water
Solids, dissolved	mg/l	As rec'd	-	-	-	-	97-9364	482-9005	1052-1079
Solids, suspended	mg/l	As rec'd	-	-	-	-	24-2010	7-5476	28-30
Solids, suspended volatile	mg/l	As rec'd	-	-	-	-	13-398	31-1534	8-14
Solids, total	% (w/w)	As rec'd		41.97-66.25			-	-	-
	mg/l	As rec'd	-	-	-	-	121-9762	605-9740	1080-1109
Starch	% (w/w)	As rec'd		0-6.0			-	-	-
Sugar	% (w/w)	As rec'd		0.003			-	-	-
		Dry		0-0.8			-	-	-
Sulfates	mg/l	As rec'd	-	-	-	-	5-1350	5-830	131-140
Sulfur	% (w/w/)	As rec'd	0.08-0.16				-	-	-
		Dry	0.13-0.14				-	-	-
		MAF	0.18-0.19				-	-	-

Parameter			Type of sample						
Identity	Unit of measurement	Basis of measurement	Municipal refuse	Compost	Incinerator residue	Fly ash	Scrubber water	Quench water	Land surface water
Volatiles, total solid	%	As rec'd	30.70-44.45	34.53-36.63			-	-	-
	(w/w)	Dry	53.03-95.7		0.2-95.2	2.5-14.0	-	-	-
	mg/l	As rec'd	-	-	-	-	105-2000	129-1106	149-231
	% (w/w) of total solids	As rec'd					11.94-86.77	10.45-58.13	13.43-21.38